SOME NEW FACTS ON THE BIONOMICS OF THE CALIFORNIA RODENT FLEAS.

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The thorough investigations which the United States Public Health and Marine-Hospital Service are at present undertaking in suppressing bubonic plague in California presented the writer with an opportunity to study the parasites associated with the transmission of the disease among rodents.

In this contribution we have not taken into account the factors involved in the epidemiology, but have restricted the scope of the paper to a discussion of the general habits and transformations of the California rodent fleas. Many of the observations on the bionomics of the fleas are quite different from those recorded by the investigators of the English Plague Commission in India. This is due in a measure to difference in climatic conditions, to which fleas as a rule are easily influenced; and the difference in the species of flea. The English workers confined their experiments to one species, namely, the *Loemopsylla cheopis* Roth. We have considered the rodent fleas generally, giving most attention to the squirrel flea *C. acutus* Baker.

FLEAS IN RELATION TO THEIR ENVIRONMENTS.

We have made an effort to rear fleas in the laboratory by attempting to duplicate conditions found to exist in nature. The human flea, *P. irritans* Linn, was found to develop very satisfactorily in a medium composed of floor sweepings taken from the cracks in the floor. The squirrel fleas and rat fleas were found to develop well in material taken from the nests of their respective hosts. We have experienced no difficulty in raising these parasites by placing animals covered with fleas in cages with a bedding of sawdust; and the only provision necessary for complete development was the addition of fresh sawdust to prevent the accumulation of too much moisture.

An experiment was made to determine in what media fleas away from the host would survive longest. For this purpose we tested various materials shown in the following table:

LENGTH OF LIFE IN VARIOUS MEDIA.

C. acutus.

Days Removed from Host	Dry Sand with Squirrel Droppings	Moist Sand from Squirrel Nest	Dry sand from Squirrel Nest	Sawdust Moistened with Horse Serum	Dry Sawdust	Moistened Sawdust with Wheat Grains
	* †					
2	5 M. 5 F.	10 F.	10 F.	4 M. 6 F.	4 M. 6 F.	4 M. 6 F.
7	2 M. 5 F.	4 F.	All dead	1 M. 3 F.	4 F.	1 M. 5 F.
9		1 F.		2 F.	2 F.	1 M. 4 F.
10	2 M. 5 F.	All dead		All dead	All dead	1 M. 4 F.
14	1 M. 1 F.					1 M. 3 F.
16	1 M. 1 F.					
17	All dead					1 M. 3 F.
20						3 F.
25						1 F.
26						All dead

*M—Male; †F—Female.

The controls 5 M. 5 F. were all dead on or before the seventh day.

In the medium of moistened sawdust mixed with a few wheat grains it was found that the wheat sprouted in the sawdust and held sufficient moisture to provide a suitable condition for larvae as well as for adults. The mould which formed in a short time did not seem to affect the insect life.

It is seen that the fleas did not fare well in the medium of dry sand. The sand was mixed with clay dust which would rise whenever the fleas hopped in the vial. As a consequence death resulted presumably by stoppage of the spiracles.

It will be seen from a survey of this table that fleas taken from the natural host may be kept alive without food for a considerable time. The medium of moistened sawdust with a few grains of wheat seemed to answer the moisture requirements for flea life.

LOCOMOTION.

The only literature that has come to our notice on the jumping powers of fleas appears in the Journal of Hygiene, 1906, Vol. 6, p. 464. Here we have a note: "It had previously been found that a rat flea could not hop farther than five inches." The species in question in these experiments was the *L. cheopis*, which is found to the extent of 99% on the rats in India.

It seemed desirable to learn the jumping abilities of the common California species. An attempt was made to determine the distance upon a horizontal plane, as well as the height that the insect could jump. In the broad jump a few experiments were conducted with *P. irritans*, the most active of our California fleas. In this species we have found the jumping distance varies considerably with the nature of the container from which the insect is observed, e. g., a foothold of wood enables the flea to jump a greater distance than one of glass. Since the *irritans* is found to predominate on floors of houses, a surface of wood was selected as the footing in our tests. In one experiment, five specimens were permitted to jump at will and the jumps of each were recorded. The mean average of ten jumps of each specimen gave a distance of 7 3–10 inches. The longest jump recorded was 11 inches; this was made by a female. In another experiment, a female, which was starved for five days prior to the test, made four jumps of respectively 10 5–10, 11, 12, and 13 inches; averaging 11 5–8 inches. Thirteen inches was the longest jump recorded on a horizontal plane. A jump of 15 7–8 inches was made downward at an angle of thirty degrees.

This specimen was then permitted to feed fifteen minutes on the arm of an attendant, after which it was carefully returned to the container, and its jumps for five minutes recorded. The longest jump after feeding was 12 inches.

The jumping powers of squirrel and rat fleas were tested in this manner: Three hundred and seventy-five live squirrel fleas (*C. acutus*) and one hundred and fifty live rat fleas (*C. fasciatus* and *L. cheopis*) were placed in two distinct lots in fifteen open specimen vials in a water bath and left undisturbed for two days. At the end of the period, the vials were examined, the water bath and the surroundings being carefully inspected. No fleas could be detected in the water bath or in the vicinity; the fleas in the vials were counted, the original number being present. They were apparently as active as when removed from their hosts. The containers were cylindrical vials 3 3–8 inches in height and 1 3–16 inches in diameter. The same test was tried in open shell vials of the next size smaller (3 1–8 x 1 inch) and the fleas were found jumping into the water bath.

L. cheopis, the rat flea, was tried for its jumping power. It had been previously observed that members of this species were unable to leap out of open shell vials 3 3–8 inches in height. It was thought desirable to permit the flea greater latitude making the trial fairer and more practical. Twenty fleas (eight males and twelve females) were placed in a rectangular porcelain dish, the dimensions of which were 11 7–8 inches by 7 5–8 inches by 2¼ inches deep. A light sprinkling of moist sand was placed in the bottom of the dish to provide a firm footing and the sides of the dish were extended to the height of 4½ inches, enclosing the container entirely by strips of "tangle-foot" paper. At the end of twenty-four hours the dish with the fleas was examined, and it was observed that several fleas had leaped high enough to become entangled on the adhesive paper. The position of these was noted, the distance from the bottom of the pan was measured. The entangled insects were pried off, the sticky material dissolved with alcohol and the insects examined microscopically. Five specimens were collected, two males and three females. The locations on the adhesive paper relative to the base of the dish were as follows:

1 F. 2½ inches	1 F. 3 1-8 inches	1 F. 2 9-16 inches
	1 M. 2 5-8 inches	1 M. 3 1-16 inches

A census of the fleas remaining in the bottom of the dish gave 6 M. and 9 F. showing that none jumped over the surrounding paper, and that all jumping over 2½ inches were embedded in the adhesive paper.

The jumping powers of *P. irritans* were further tested, twenty fleas of this species being placed in a rectangular museum jar, the inside dimensions of which were 2¼ x 5½ x 7¾ inches depth. The glass lid of the jar was coated with "tangle-foot" and the sides of the jar within two inches of the top were likewise coated, with the same material. The following morning the jar was examined and two specimens were seen embedded in the "tangle-foot" on the lid. The inside height of the jar being 7¾ inches from the base gives then this height as the perpendicular jump.

Concerning the fleas ability to walk upwards on glass, we have noted that they cannot climb to any considerable distance. A great number of counts were made, the greatest distance observed being ¾ inches. The climb appears very laborious and in all cases the flea dropped to the bottom of the jar after a few efforts.

We have observed the manner in which these insects can find their way about upon their natural hosts. They pilot their paths among the dense hairs, walking on the flat of their tarsi, seeming to shuffle along. When on the animal they seldom hop about, unless disturbed or unless the host snaps at them or scratches when unusually annoyed. They hop freely when jumping from the animal to the ground or vice versa, or from one host to another. When a flea is cornered, that is, when it experiences difficulty in passing an obstruction, it proceeds like a swimmer using the side stroke. The parasite drops to its side and locomotion ensues by a vigorous sweeping movement of the legs, almost entirely by the use of the hairs and spines, especially through the medium of the powerful spines of the tibia, when it ambles along on the flat side in a striking manner. The spines of the leg seem to be peculiarly adapted for this side motion: it is in this fashion that the nimble parasite manages to become so very elusive. We refer especially to the *P. irritans*. This may be tested by holding a live flea between the thumb and forefinger and unless you chance to be a flea trapper of long and painful experience the ingenious parasite will surely escape.

CONSIDERATION OF COLOR ATTRACTION.

We have a little experimental evidence on the question of attraction of these insects towards color in animals. It is the prevailing opinion that white animals attract the greatest number of fleas. We have to report a few tests of color attraction. The material used in the first experiment was six guinea pigs showing extreme variations of color: three of these were pure white and three pronouncedly dark. These were placed in a large cage, the bedding of which was infested with squirrel fleas. After forty-eight hours the guinea pigs were removed simultaneously and a census of the fleas on the individual animals was made immediately. Fleas and animals were anaesthetized at the same time, the white guinea pigs yielding respectively ten fleas, five fleas, and eleven fleas. The black guinea pigs yielded eleven, seven and four fleas; the last number came from a mixed black and white guinea pig. A summary of the fleas from the three white guinea pigs gave twenty-six fleas, or an average of about nine each; the two dark guinea gigs giving eighteen, averaging nine each, and the black and white giving four fleas, all of which were of the species, *C. acutus*, the squirrel flea.

A second experiment was as follows: Four guinea pigs were placed in a large container, which was swarming with squirrel fleas. After three days the animals were removed as before, and a census of the parasites was taken: one brown and black guinea pig yielded eighty-nine fleas; another brown and black guinea pig yielded fifty-seven fleas; a pure white guinea pig yielded fifty-seven fleas; and the other white guinea pig yielded sixty fleas. These guinea pigs were kept together in the open vessel under the same conditions of light and temperature.

One experiment was conducted by using guinea pigs as traps for fleas in an infested house. The results shown are relatively meager due to the previous use of adhesive paper for flea trapping. In this test six guinea pigs were permitted to wander for twenty-four hours through the basement of the house. The fleas collected from the guinea pigs were *P. irritans* found on the hosts as follows:

Color of animal	Number of fleas
Black guinea pig	1
White guinea pig	1
Black guinea pig	1
White guinea pig	1
Black guinea pig	0
White guinea pig	0

It is obvious from these experiments that color does not exert the influence generally claimed for it. The white animals are no more attractive to the fleas we have used than are the dark colored ones.

TRAPPING OF FLEAS WITH MEAT AS A BAIT.

An idea prevails that fleas can be attracted and trapped on account of their predilection for the odor of fresh meat. This idea was put to test in an experimental way. On the 23rd day of August, 1909, during a season in the year in which fleas were extremely abundant, a vacant house, which was found to be flea infested, was chosen for the experiment. To give an idea of the abundance of the parasites, two attendants, who had occasion to enter the first floor of the dwelling, remained for the period of five minutes and emerged covered with fleas. Approximately two hundred fleas were taken from their clothing and persons. The materials used for the experiment were twelve sheets of "tangle-foot" fly paper, distributed in pairs among three rooms of the house. One sheet of each pair was supplied with a small fresh piece of cow's liver. Care was taken to distribute the sheets in such a manner that the influence of light would be the same for each pair of sheets in the series. The sticky fly papers were left undisturbed for a period of three days, then collected and examined.

A similar experiment was conducted at a later date, December 5th, 1909, when San Francisco dwellings were still flea infested. The sheets of fly paper were left in the basement of the house for twenty-four hours. The fleas in both experiments were removed by dissolving the "tangle-foot" in alcohol. The parasites which were all identified as *Pulex irritans*, were distributed on the sheets as follows:

Total number of fleas trapped.

	Experiment 1		Experiment 2	
Pair	Adhesive paper with meat	Adhesive paper without meat	Adhesive paper with meat	Adhesive paper without meat
1	0	0	2	4
2	2	2	1	3
3	2	1	6	4
4	0	3	47	49
5	6	12	1	0
6	4	1	4	1
Totals	14	19	61	61

The table shows that according to our experience, though the data is limited, meat used as a bait under the conditions stated does not exert any special attraction for fleas.

COPULATION AND EGG LAYING.

The most prolific of the rodent fleas, *Ceratophyllus acutus* was set aside for studies in mating. The fleas were observed in nature in relation to the host, then microscopically. For the purpose of close observation, a live ground squirrel (Citellus beecheyi) was placed in a mouse jar, where it was kept for a few hours under surveillance. It was noticed that when the animal's body was pressed against the glass that the pelage parted in furrows made by some active objects close to the skin. It was apparent that the squirrel was harboring a large number of active fleas, which occasionally came to view mounted on the hairs of the host.

The attention of the observer was attracted by a number of fleas which appeared gigantic in size. These proved on close inspection to be paired. Approximately 1 to every 3 of the total number of fleas infesting the squirrel appeared thus in copulation. The female of the pair covered almost entirely the body of the male, which was quite lost to view, only the hind legs projecting beneath the abdomen of the female. The pair in copulation was observed never to feed, moving about as one insect; and anomalous as it appears, the member on the ventral side, the male, contributed no effort in the locomotion during the nuptial wanderings. His fore and middle legs doubled under the sternum, the hind pair extending stiffly as though paralyzed beneath the abdomen, where they were held securely by the tarsal spurs of the female interlocking with the tibial spines of the male.

The locomotory function was accomplished by the female, the front and middle legs of which were used freely in walking; by releasing temporarily the entwining spines of the hind legs she was able to leap at will. In this manner, the female moved about on the body of the host as though unhampered by its anchored mate.

Seven pairs of these fleas were collected from the live squirrel with the aid of a camel's hair brush, placed in cell slides and covered with glass slips. They were observed under the low power microscope, then kept in separate vials, one to several hours until the function was completed.

As observed microscopically, the male adheres to the female by the pseudo-joints of the terminal segment of the antennae. This attached appendage is extended and pendant, interlocking by its hairs the bristles on the ventral side of the second abdominal segment of the female. The hind femora of the latter grasps the male by the head at a point anterior to the antennal groove. The head of the male is held in position between the inner sides of the meta-femora of the female. The tarsal spurs of the female entangle the spines of the hind tibia of the male. The smaller of the pair thus suspended assumes the passive role moving at the volition of the female.

The copulatory act is manifested in the male by the watch-spring like action of the spiral, which, coiling and uncoiling intermittently extends and withdraws the terminal apparatus.

The male claspers are seen on either side of the vaginal groove of the female directly below the anal flap. The male makes a distinct concavity in the caudal portion of the back; with the strong action of the muscle attachments the plate of the penis is made very elastic. The spasmodic pulsations of the curled up abdomen are followed by a current of bubbles passing through the genitalia of the male upwards to the female. The spermatheca of the latter is faintly discernible during the act as it swells and collapses. The length of time involving coition in the fleas under observation varied a trifle less than two hours to four and a half hours. The movements preliminary to the act were not noted.

The male makes the first effort to disconnect or disentangle the pair. In one instance, the male attempted to free itself by pressing vigorously the mid and hind tarsi against the hind tibia of its mate. Simultaneously, the antennae were torn from the recumbent spines of the abdominal segments of the female. The abdomen was straightened, relaxing the clutch of the claspers; the spiral contracted releasing the intromittent organ, and a final kick of the hind legs gave the male its liberty. The female was seen on ten distinct occasions to approach the male, and the latter repelled the advances of its larger companion; at each contact of the female, it would jump in the air, attempting to remain on the opposite side of the vial.

Mammalian blood appears essential for fleas to partake of normal functions of copulation and oviposition. In our experience insects kept constantly in jars and reared from cocoons never having been fed upon a host have not been observed to copulate or oviposit. In thirty specimens of *P. irritans* taken from a house which had been vacant for six weeks we found, after three days observation, that the fleas were perfectly healthy; and although females predominated no eggs were found at the end of this period. As a control, six females of this species collected from human hosts when kept in separate vials laid eggs normally, depositing from 5–12 in each instance.

Four experiments with *C. acutus*, the squirrel flea, have given results similar to the foregoing, namely, that this species when reared from cocoons and kept starved in jars at room temperature has not been observed to mate or lay eggs.

In twenty-five paired specimens of several species kept under observation it appears that the male does not long survive the act of mating. It dies even before the female has laid its first batch of eggs. When fertile females are kept under artificial conditions the eggs are laid in one laying in a period beginning two hours after copulation and extending to a maximum of thirty-six hours. When deprived of food the female has never been observed to oviposit after this length of time.

We may note here that when used experimentally the female is invariably longer lived. Experiments to determine length of life with human blood diet show that female fleas of all species outlive the male by several weeks. This is doubtless true also under natural conditions, where we find in collecting fleas from the host that the females predominate markedly.

The eggs require optimum conditions of temperature and moisture for hatching. They have never been found on the host except in one instance. In this case a dog was used in the laboratory for supplying fresh fleas; this was done by placing the canine on sheets of paper which in a few hours were littered with a large number of flea eggs. These were laid loosely on the host by the fleas, the eggs falling to the paper, where they were collected. Flea eggs have never been found on man, and if present, would not hatch under normal conditions of the body temperature. We have found that keeping eggs in the incubator at blood heat is sufficient to prevent hatching. If the eggs were laid on the host we would certainly expect to find them on the squirrel, on which animal fleas are most abundant. We have taken from two squirrels, respectively, 225 *C. acutus* and 376 of the same species; but in no instance even where fleas are present in such large numbers have we been able to find eggs even after carefully combing the host. The *C. acutus* is by all means the best criterion in this matter, since we have found that it lays more eggs than any other of the rodent fleas.

The eggs are laid singly in small clusters, and may be viscous as in *P. irritans*, *C. fasciatus*, *L. cheopis*, *C. acutus;* or dry as in *C. canis* and *C. musculi*. The former adhere to the medium in which they are laid, and the eggs of the last two species are laid loosely, so that they roll when shaken in the vial containing them.

Eggs may be laid while the insect is still under the influence of an anaesthetic; when covered by a glass slip; and when exposed to strong sun light.

It appears to be the first impulse for the female to lay its eggs when removed from the host and placed under artificial conditions. The great majority of the eggs obtained were laid on the first day, beginning almost immediately after the fleas were captured. It is a common observation that many females with their abdomens distended lay their eggs as soon as the vial is closed over them. The number of eggs laid at one laying by different species, varies from 3 to 18; the rat fleas averaging 6 and the squirrel fleas lay as many as 18.

THE PROCESS OF HATCHING.

C. acutus.

Six eggs laid while the females were kept under observation were examined from time to time until hatched seven to nine days later. One egg, was observed microscopically during the entire process; the other five eggs used as controls were examined occasionally.

On the seventh day of incubation at room temperature the premonitory signs of hatching were discerned in a very faint rising and falling of the exochorion (outer shell layer) on one side of the shell. During the night, seven hours later, the movement grew more extensive, the pulsations becoming quite pronounced, causing the egg to shift slightly from its position. On the morning of the eighth day a deep gash was observed in the side of the egg. The gash is made by the egg opener, a wedge-shaped, horny, claw-like structure on the dorsal side back of the head of the embryo. This is operated so as to hew through the resistant shell by a series of slits or gashes. The initial gash increases slowly in length, encircling the egg within an hour.

In the course of a few hours, seven successive gashes are made, the location of these is quite constant; two on each side of the egg and three at the center, the middle of the latter being the most distinct. The young worm produces these slits through the chorion (inner skin of shell) by turning with its dorsal side against the shell, striking with the egg pick first against the base of the egg, rising on its hind prolegs and striking rapidly as it climbs upwards. Prior to each stroke the egg pick is poised deliberately, the weight of the head accelerating the blow; this is augmented occasionally by a lateral shaking of the head.

When the last slit encircles the shell, the embryo is at the most active stage, it effects a complete rotation in its shell at intervals of ten minutes. The gashes make the shell appear as though cut into ribbons. The rotary movement gradually subsides until a complete turning consumes twenty minutes, and almost imperceptibly there follows a lull. An inactive almost comatose condition prevails for a period of about seventeen hours. After the resting period, it appears that the egg pick is no longer functional; no new gashes are made, the embryo seeming contented to concentrate its energies against the middle gash.

This is enlarged by a puffing and dilating of the head; through the semitransparent shell is seen a constant bubbling and a subsequent dilatation of the cuticle.

On the third day of the hatching process, a strong movement of the embryo gives decided evidence of the progress of hatching. Immediately behind the egg pick, a triangular slit appears through which bubbles emerge to the surface of the exochorion; thus the amnion (the embryonic cuticle) makes its initial appearance through a crack in the exochorion of the shell.

The amnion splits longitudinally adhering to the chorion and bulging out as the insect struggles. It is pushed out of the chorion as the abdominal segments are projecting. The emergence is furthered by the young maggot pressing the head against its tail causing the middle of its body to bulge through the central gap of the shell. The amnion becomes noticeably darker as it is exposed to the air; it is now a light brownish-yellow.

The pressure of the body against the shell forms nearly a round hole through which the larva eventually emerges. The opening is enlarged by pressure of the head against the tail, raising the body like a hoop, causing an arch or a hump to appear with dorsal side outwards.

The amnion sheds slowly on either side from the middle of the arched abdomen ventrally and with a movement of fluid beneath it cracks across the abdomen, peeling and wrinkling as the segments telescope. With a final vigorous bubbling and wrinkling the amnion sheds off, the moulted skin falling on either side, exposing the quite colorless cuticle of the maggot roughly wrinkled and bristling with slender hairs. These hairs which at first appear transparent turn grayish when exposed to the air.

When the tail of the larva has been torn loose from the shell, the head and thorax are still imprisoned within the egg, necessitating a maneuvering by waving its tail in the air, twisting and squirming while standing on its head. The abdomen doubles up ventrally and finally the young larva supported on its tail extricates the head by a violent shaking. When the head is torn from its fastenings, it is found that the amnion has been holding it within the shell. The adhering membrane is cast out when the shell is shaken off. The larva has now fully emerged, the colorless cuticle has turned grayish and the slender threadlike bristles have assumed an iridescent hue.

The larvae upon hatching busy themselves immediately in the quest for food. They experience little difficulty in locating it, for at the time of birth a supply of food is found upon the egg shell. Here they feed from the first on the tiny blood pellicles surrounding the egg shell; this the mother furnishes when the egg is laid. When the last of the egg pellicles of blood are consumed, the insatiable worms look about them for other sustaining morsels. The dejecta of the adult flea seems to provide the desired ingredients. The young larvae feed ravenously on the bloody deposits, apparently satisfied to pass the first few days on this unique diet. They can subsist entirely on the bloody fragments (flea faeces) when no other food is available, for a period of five to six days.

THE REACTION TO LIGHT.

The larva is positively heliotropic up to the stage of the initial moult. The more advanced sluggish larvae are repelled by the light. This is seen when examining the flea breeding cages a slight stirring of the nesting material attracts to the surface the tiny very active larvae. If the older larvae are desired, it is found necessary to nearly invert the container. Prior to the final moult when the larva is in readiness to pupate it can be seen almost invariably along the edges at the bottom of the box, where the greatest number of cocoons are brought to view.

TROPIC INFLUENCES IN THE ADULT FLEAS.

Rodent fleas are negatively phototaxic (repelled by light) to a very striking degree. The first impulse seems to be to seek protection from the light. This is seen in combing a squirrel or rat recently killed; the fleas will retreat constantly to the underside, always in the direction away from the light. When shaken off, they return to the shadow of the host; in numerous instances even when the animal was dead for a period ranging from 24 to 50 hours the fleas when shaken off would seek the host and bury themselves under the hairs away from the light.

When a number of live squirrel fleas and rat fleas were placed in an open test tube and held horizontally with the operator's thumb covering the mouth of the vial and the bottom held against the window, the fleas crowded towards the open mouth in the direction of the thumb, bounding away from the window in an excited manner. When the tube was reversed with the open mouth towards the window, it was found unnecessary to plug the mouth of the tube as the fleas did not attempt to jump out when given an opportunity to do so. Even when placed within a half inch of the open end of the tube with the head of the insect turned towards the light, the fleas reversed and jumped towards the closed end of the tube. This was repeated by tilting the mouth downward to offer an easier exit through the open mouth; but even this inducement did not influence the fleas, which invariably sought the closed end of the tube in the shadow. This was tried with squirrel and rat fleas as well as with human fleas and always with the same result.

LONGEVITY OF THE CALIFORNIA FLEA.

The great life of our native parasites seems to be anticipated at the very incubation. Eggs are laid at all times. We have observed oviposition during every month. The broods appear to be constant and the number irregular. The incubation stage of our Eastern forms taken from the observations of Pergande consumes 2–4 days ordinarily. Two days is given as the incubation period for the *cheopis* in India. Our experience with this species is a duration varying from 9 to 13 days at room temperature. When eggs of this species were subjected to identical conditions in which wild rats were caged in the laboratory basement (at a temperature of 20° to 25° C.) the length of the egg stage was 19 days.

Larval life is cited by Eastern and English authorities as a minimum of 8 days and a maximum of 24 days. The larval stage of our California fleas under laboratory conditions is never less than 28 days, often 30 days and sometimes longer.

Pergande found that the pupal or cocoon stage of the *Pulex irritans* varied from five to seven days in the summer months at Washington. Other authors working with this species give twelve days during summer months. We have observed several instances of cocoon life during the warm days of September. Thirty days appear to be spent in this stage.

The entire life cycle including adult life is given by several authors as four to six weeks. The British Indian Plague Commission gives as the time necessary for the completion of the cycle of development (in the case of *L. cheopis*) that is from the egg to the imago, as 21 to 22 days.

The following is given as a type of the life cycle observed in *C. acutus*. This specimen was kept under observation from the moment the egg was laid by its parent. An hour after the egg was laid it was placed in a small vial with a little sawdust, sand, wheat grains and squirrel hair. It was allowed to develop in this environment until matured.

Stage of development	Date	Age of flea
Egg laid	May 4th, 1909	
Hatched	May 12th, 1909	8 days
Moulted (second stage)	May 18th, 1909	14 days
Moulted (third stage)	May 28th, 1909	24 days
Cocoon	June 9th, 1909	36 days
Adult	July 10, 1909	67 days
Alive (never having been fed)	Aug. 11, 1900	99 days

The English workers in India ascertain the length of time which adult fleas live on rats as 41 days. The longest life of this species on an exclusive diet of human blood was observed to be 27 days. We have managed to keep this species (*cheopis*) alive for a period of 36 days by feeding on man. The length of life without feeding was also noted. This period varied in the experiments of the English Commission according to the environments in which the fleas were maintained. In the absence of liquid food supply, fleas could live in bran for six days, in gunny sacking a similar time, and in sand with moist cowdung for 13 days. From onr observations we have found the majority of fleas of all species to die in five days unless a moist medium was provided.

As we have stated above rat and squirrel fleas may be kept alive for a considerable time when moisture is provided in some form. It is interesting to note that fleas which have never tasted animal food, having emerged from the cocoon and kept under the same conditions in similar material as fleas taken directly from the host, will prove longer lived. A number of specimens of *Ceratophyllus acutus* removed from a ground squirrel and kept in moistened wheat grains and sawdust lived for 26 days. An equal number of fleas of the same species bred from cocoons in the laboratory were kept without a host in a similar medium. One male lived 38 days and a female lived for 65 days.

In a series of experiments in which fleas taken from healthy rats and squirrels were fed daily on the arm of a man we attempted to determine the maximum longevity of these parasites. The fleas were placed individually in open test tubes and at feeding time the tubes were inverted over the arm of one of the laboratory attendants. Fleas were thus applied daily for a period of from 5 to 15 minutes, but only the actual feeding time was recorded. The average was about five minutes.

A *Loemopsylla cheopis* was fed for 35 days, escaping on the 36th day. One *C. acutus* died after 58 days and another one at the end of 51 days. The common brown rat flea *C. fasciatus*, proved to be the most persistent feeder of them all. Unfortunately one of them was permitted to escape after feeding on its induced host for 63 days. Another of the group suffered no ill effects from its enforced diet for 98 days; and the sole survivor had been nourished by its foster host since its removal from the rodent host for a period of five months. The experiment was discontinued, but the parasite survived a week longer in a starved condition.

LONGEVITY RELATIVE TO SEX.

We have noted the relative longevity of the sexes under the conditions of experiments in which fleas were fed on human blood alone.

We shall take for consideration the two species common to rats, *L. cheopis* and *C. fasciatus* and the predominant squirrel flea, *C. acutus*. Four tests with *C. fasciatus* gave the following data:

C. fasciatus.

Six males of this species averaged 8½ days, the maximum life being 17 days. Fifteen females gave an average of 32 4-5 days with a maximum of 125 days. The two unfed controls (male) of this series lived for 3 days, and the two control females lived for 5 days.

L. cheopis.

Two tests with a total of seven males of this species gave an average of 10 1-7 days and a maximum period of 15 days.

Three females lived 28 1-3 days as an average and a maximum period of 49 days.

The two unfed male controls lived 5 days and in four females the average was 5½ days and the maximum 7 days.

C. acutus.

One test with this species furnishes the following data: Three males averaged 11 days, and gave a maximum of 11 days.

Five females averaged 15 1-5 days. The longest life was 53 days.

The unfed males averaged 3 days and showed a maximum of 4 days. The female control lived 5 days.

The greatest length of life of a male of any species is seen to be 17 days; and the term of life under these conditions for a female was 125 days, somewhat over 4 months.

In these tests for longevity, it should be borne in mind that no attempt is made to arrive at the initial age of the fleas, but the time is reckoned from the day of removal from the host.

An effort was made to determine the length of adult life of one species, *C. acutus*, by feeding the insect newly emerged from the cocoon. Ten specimens emerging within a few hours of each other were fed on the same day on human blood. One specimen, a female, lived for sixty-four days; at which time the experiment was discontinued. The unfed controls, as well as the specimens given a human blood diet, were kept in ordinary test tubes at room temperature. The activities of these fleas may have been influenced by changes in the temperature and the absence of moisture in the tubes.

NOTES ON THE FEEDING PROCESS.

There is a remarkable degree of variation in the feeding habits of the different species of fleas. We have not attempted except in a superficial way, to study the idiocyncracies of the rodent fleas in regard to the biting of their normal hosts. We have, however, quite thoroughly observed the manner of biting under experimental condition with man as a host. Without taking into account the attraction or repulsion which may be exerted towards man as a host, we shall consider the more striking features of the biting of the parasites. We find that the species do not all attack with equal avidity. *Pulex irritans* the ectoparasite of man, is insatiable in its blood craving. It differs in its relation to man in being more fastidious in its feeding than the rodent fleas. Although its bite is painful, it does not voluntarily feed in one spot for any great length of time. The *Pulex irritans* differs from all other species (hundreds of specimens of which were tested on human hosts) in that it squirts blood per anum during the act of biting.

The *L. cheopis* and *C. fasciatus*, the normal rat parasites, are found to bite man with equal readiness and will live about the same length of time when fed on human blood. Their biting is well defined and effective, but not nearly so painful as that of *Pulex irritans*, nor so prolonged as the common squirrel flea, *Ceratophyllus acutus*. A specimen of *C. acutus* when starved for several days has been observed to feed on man uninterruptedly for a period of nearly one hour (59 minutes) at one insertion of its proboscis.

The bite of the *Ctenopsyllus musculi*, the blind flea of the mouse, is the feeblest we have had inflicted from any flea tested. The short weak piercing organs of this species makes a puncture, which is scarcely perceptible. In observing the length of time this flea bites, it is necessary to depend as a guide on the distention of the abdomen with blood rather than the prick of the mandibles. The *musculi* seems not able to adapt itself as an induced parasite of man. From a few experiments it appears to live not longer than five days on a human host.

The *Ceratopyyllus acutus* which proves a very ready parasite of man makes its attack even without inducing experimentally. Our data compiled from reports and collections of squirrel hunters shows that this species, as well as the other common squirrel flea, *Hoplopsyllus anomalus*, will bite man when exposed to their attacks.

The unusually long rostrum in this flea is presumed to be the cause of its prolonged feeding at one insertion of the mouth parts. This principal is not unprecedented judging from a study of numerous parasites in the insect world.

The following is the description of the method of feeding observed in *C. acutus*. This method is typical.

The flea when permitted to walk freely on the arm selects in a few minutes a suitable hairy space where it ceases abruptly in its locomotion, takes a firm hold, with the tarsi, projects its proboscis and prepares to puncture the skin.

A puncture is drilled by the pricking epipharynx, the saw-tooth mandibles supplementing the movement by lacerating the cavity formed. The two organs of the rostrum work alternately, the middle piece boring, while the two lateral elements execute a sawing movement. The mandibles, owing to their basal attachments are, as is expressed by the Journal of Hygiene, Vol. 6, No. 4, p. 499, "capable of independent action, sliding up and down but maintaining their relative positions and preserving the lumen of the aspiratory channel." The labium doubles back, the V-shaped groove of this organ guiding the mandibles on either side.

The action of the proboscis is executed with a forward movement of the head and a lateral and downward thrust of the entire body. As the mouth parts are sharply inserted, the abdomen rises simultaneously. The head and middle legs are elevated resembling oars. The fore legs are doubled under the thorax, the tibia and tarsi resting firmly on the epidermis serve as a support for the body during feeding. The maxillary palpi are retracted beneath the head and thorax. The labium continues to bend, at first acting as a sheath for the sawing mandibles, and as these are more deeply inserted, it bends beneath the head with the elasticity of a bow, forcing the mandibles into the wound until the maxillae are embedded in the skin of the victim. When the proboscis is fully inserted, the abdomen ceases for a time its lateral swinging.

The acute pain of biting is first felt when the mandibles have not quite penetrated and subsequently, during each distinct movement of the abdomen. The swinging of the abdomen gradually ceases as it becomes filled with blood. The sting of the biting becomes gradually duller and less sensitive as feeding progresses. The movements of the elevated abdomen grow noticeably feebler as the downward thrusts of the springy bowlike labium become less frequent.

As the feeding process advances, one can discern through the translucent walls of the abdomen, a constant flow of blood, caudally from the pharynx, accompanied by a peristaltic movement.

The end of the meal is signified in an abrupt manner. The flea shakes its entire body, gradually withdraws its proboscis by lowering the abdomen and legs, and violently twisting the head.

When starved for several days, the feeding of the rat fleas is conducted in a rather vigorous manner. As soon as the proboscis is buried to full length, the abdomen is raised and there ensues a gradual lateral swaying motion, increasing the altitude of the raised end of the abdomen until it assumes the perpendicular. The flea is observed at this point to gain a better foothold by advancing the fore tarsi, and, then gradually doubling back the abdomen, it turns a back spring, with extreme agility, nearly touching with its dorsal side the skin of the hand upon which it is feeding. Meanwhile, the hungry parasite feeds ravenously.

It is interesting to note the peculiar nervous action which the rodent fleas exhibit immediately when the feeding process is completed, or when disturbed during the biting. Even while the rostrum is inserted to the fullest, the parasite shakes its head spasmodically, in a twinkling the mouth is withdrawn and the flea hops away.

POSSIBLE VITAL CONSIDERATIONS INVOLVED IN FEEDING HABITS.

We have previously noted that rodent fleas can live in a starved condition, away from the host, during a period of three to ten days, when kept in dry test tubes; as long as twenty-eight days when a suitable moist medium is furnished. The long periods of starvation appear not to affect the vitality of the parasite to such an extent that the ability to feed is impaired. We have recorded instances in which a specimen of the squirrel flea *H. anomalus* starved for sixteen days, and several specimens of *C. acutus* starved for twenty-seven days had sufficient energy to feed 10–15 minutes when an arm was placed in the breeding jar. These facts lead us with others to accredit in a measure the claims of older authorities on plague, who contended before the flea theory was recognized, that clothes and baggage of an infected community harbored the germs of plague, which remain viable during long period of time. Modern writers have called our attention to the plausibility of infection in clothes and baggage due to the agency of fleas, which may be transported from infected communities. Bannerman (Journal of Hygiene, Vol. 6, 1906, pp. 189–191), writing on the possibility of the spread of infection by means of clothes, brings forth several instances in which conveyance of infection by clothes seemed the most likely means of introduction of plague in some villages in India. Plague infected rat fleas secreted in the clothes en route are held responsible for the transmission. Bannerman cites an instance of plague transmission through clothing where as much as ten days elapsed in the transportation of clothing removed from a plague infected victim and worn by a relative of the deceased, who in turn contracted the disease.

It has not been our intention to enter into a discussion of the flea from the standpoint of plague epidemiology; it is desired merely to indicate the possibility that starvation of infected fleas may not eliminate the danger of transmission. The presence of plague bacilli in rodent fleas as pointed out by the English Plague Commission (Journal of Hygiene, Vol. VIII, p. 261) does not appear to affect the rate of mortality in these insects.

SUMMARY OF RESULTS.

1. The breeding of fleas under laboratory conditions can be carried on quite satisfactorily when there is furnished a medium simulating the nest of the host. It will be seen that fleas taken from the natural host can be kept alive without food for a considerable time, providing the proper moisture conditions are maintained. A medium of moist sawdust with a few grains of wheat prolonged the life of these insects to twenty-six days. Those without this medium under the same conditions, died on the seventh day.

2. Rat fleas namely, *L. cheopis*, *C. fasciatus* can not jump higher than 3 1–8 inches.

P. irritans, the human flea, was found to make a perpendicular jump of 7 3–4 inches and as far as 13 inches on a horizontal plane.

3. Experiments with black and white guinea pigs show that in relation to color attraction white animals are no more attractive to the fleas than are the dark colored ones.

4. Experiments with adhesive paper baited with meat, demonstrate that fleas can not be trapped by the odor of meat.

5. In the mating of fleas, the female takes the initiative and the male assumes the passive role.

6. Fleas reared from the cocoon kept without a host have never been observed to copulate or oviposit.

7. The eggs are never laid on the host. Oviposition takes place within thirty-six hours after the female is removed from the host.

8. The process of hatching consumes a period of 3–4 days. The embryo breaks through the shell by means of a special egg pick, which is instrumental in the emergence.

9. The larvae can live on the bloody egg pellicles and the dejecta of the parent for a period of 5–6 days.

10. The larvae are positively heliotropic in the early stages and repelled by light in the later stages.

11. Adult fleas are negatively phototaxic.

12. The California rodent fleas have a greater life in all stages than fleas of the Eastern United States and India. The

average length of the stages of development, in *C. acutus* as a type, are as follows:

Egg stage	8 days
Larval stage	28 days
Cocoon	31 days
Adult without host	32 days and longer

13. Fleas which have never been fed from the time of emergence from the cocoon prove longer lived when starved than fleas removed from the host.

14. Rat fleas may be kept alive on a human host for a considerable time, one specimen being kept alive as long as five months.

15. The females of all species of fleas are considerably longer lived than the males.

16. Induced parasitism of rodent fleas on man seems to be influenced by the length of mouth parts in the different species. One specimen of *C. acutus*, the species with the longest rostrum, fed for a period of nearly one hour at one insertion of the mouth.

17. It is indicated that starvation of infected fleas, when these insects are transported in clothing, may not eliminate the danger of transmission of plague.